The investigation of mechanical and microstructural behavior of A537 Cl2 sheet after cold forming by press

Mohammad Mahdi Esfahani[1], Alireza Nouri[2], Mojtaba Esmaeel zade[3]
Mahdi9130720@yahoo.com

Abstract

The present study is used for the sheet forming of pressure vessel under pressure of cold forming in the open -die process. The radius of the die was 2500 mm and a sheet of A537 CL2 was used with 55 mm thickness. This process was carried out by a hydraulic press of 1000 tons. The number of stages for the forming process, in this study, are 3 stages and at each stage of the process, the sheet was under the force of 600 tons. The process was performed in one, two and three stages, in order to pinpoint the sheet forming and getting to the desired radius and to investigate the effect of repetition of the forming on mechanical and microstructural properties of the sheet. The results of the experiments showed that by forming process, tensile strength and yield stress were decreased in the first step and by repeating the process of mechanical properties, they increased, so that in the third stage of the process, mechanical properties of the initial sheets were improved and by increasing the number of process steps, the orientation of the grains is in line with the compressive strength that leads to improving mechanical properties.

Keywords*:* Cold forming, Press, Pressure vessel, Steel.

[1] Master of Science in Material Engineering, Machine sazi Arak Company.
[2] Engineering Manager of Metallurgy Group Machine Sazi Arak (a.nouri@msa.ir).
[3] Assistant Professor, Persian Gulf University, Bushehr (m.esmaeilzade@pgu.ac.ir).

1- Introduction

Simple carbon steels have widespread use in the industry. ASTM A537 Cl2 is a carbon - manganese steel that is used in pressure vessel. This steel due to its proper welding, high mechanical properties and adequate resistance to corrosion is used in the military, maritime, pressure vessel, petrochemicals, oil and gas. Therefore, according to standard, ASTM are used to construct pressure vessel and equipment at moderate and lower temperatures and to construct equipment that containing excellent toughness of the material are highly important for them [4 - 1]. In the industry, pressure vessel are made from A537 sheet with rating of Cl1, Cl3, and Cl2. However, the most popular sheet for constructing pressure vessel is A537 Cl2 sheet. The main reason for the widespread use of A537 steel plate in the construction of pressure vessel is the simultaneous availability of strength and flexibility and ability to absorb impact energy at low temperature [9-5]. According to the ASME SEC VIII standard, the pressure vessel are told the vessel that their inside pressure is more than 15 psi (and less than 3000 psi) [10]. These metal vessel are usually cylindrical or spherecal, and they are used for holding or doing chemical processes of liquids or gases, which have the ability to resist different pulses (internal pressure, external pressure, and vacuum inside). For the cortex of many closed- pressure vessel, depending on the used conditions and the wall-thickness of reservoirs, the rolling and coil sheets are used, which are bent by the forming process. The main use of these thick wall vessel is in the oil and gas industries and petrochemical industries. The aim of this study was to investigate the mechanical and microstructural behavior of A537 Cl2 steel after shaping in different stages of the forming process by hydraulic press, and to find the reason for changing mechanical properties.

2- Materials and research methods

In the present study, a A537 Cl2 steel plate with dimensions of 55 * 400 * 500 mm was used, and its chemical composition is shown in Table 1.

Table 1: Chemical composition of steel sheet

Element	C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Al
Weight percent%	0.17	0.29	0.004	0.021	1.56	0.21	0.04	0.02	0.02	0.041

The forming of A537 Cl2 sheets was carried out by 1000 tons hydraulic press, and the force used in this study was 600 tons. The process of forming the sheets for pressure vessel is a Cold Work, so it is accompanied by a spring back phenomenon. In order to reduce this effect and achieve to the final formation of sheets, the process is repeated in different stages and in this study by three stages of formation, it achieves to the final shape. The used sheet was produced by rolling process and then it quenched tempered. The method that was implemented to form the sheets was in the open die that was carried out with a punch force and die of 2500 mm radius. The way the process is implemented is after placing the sheets within the die, the force of 600 tons was applied by press to the sheet, and after applying the force, a sample was chosen from the mentioned sheet to investigate the mechanical and microstructural properties. In order to investigate the effect of repetition on the process of changing mechanical and microstructural properties and also to achieve to desired shape, the process was repeated in two and three passes and in each stage, some sample were chosen to investigate the mechanical and microstructural properties of the deformation sheet. In order to investigate the variation of impact energy in the observed passes of the process and the comparison with the sample of initial Sheet, the sample was prepared based on the ASTM A370 standard, which is schematically shown in Fig. 1.

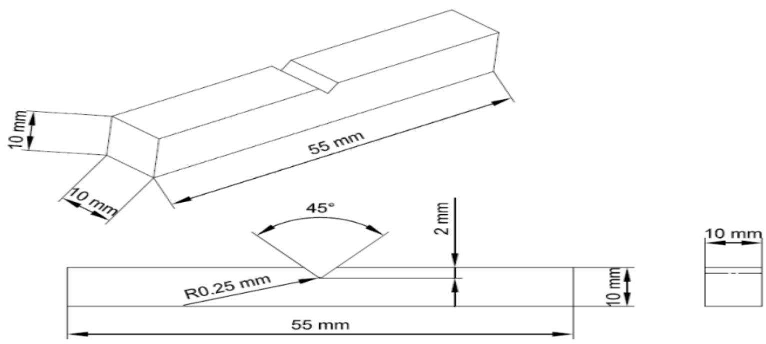

Figure 1. Shape of sample prepared for impact test.

The samples were prepared in order to evaluate the impact resistance in longitudinal direction of the sheet. Charpy Impact Test was performed at -49 ° C on the sample of the initial sheet and on the deformation sheet after one, two and three passes of the process. The required temperature was done test by the dry ice for the impact. It should be noted that the impact test device, the Santam machine is made in Iran. The tensile test samples were prepared in accordance with the ASTM A370 standard, which is schematically represented in Fig. 2.

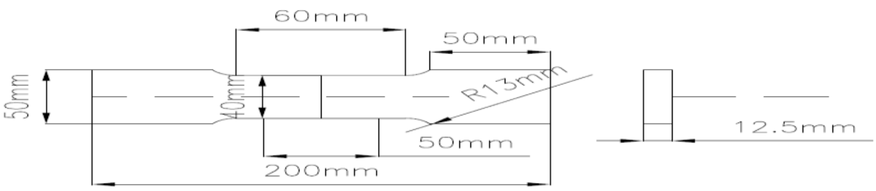

Figure 2. Shape of sample prepared for tensile test.

The tensile test device, Zwick machine used in this study is made by Germany. In addition, for the microstructural study, the parts were prepared from the initial sheet (rolling sheet) and deformation sheet and after polishing by 2% Nital solution, they were etched and then they were investigated by Optical microscope. The scanning electron microscope was used to study the fracture surface of the samples and also to determine the type of soft and brittle fracture.

3- Results and Discussion

The results of the tensile test on the deformation samples and the initial sample are shown in Table 2 and Fig. 3.

Table 2: Tensile properties of the sheet before and after deformation

Sample Name	Yield stress(MPa)	Tensile strength(MPa)	Strain Failure%
Initial Plate	513	636	11
One Pass	493	622	9
Two Passes	495	628	10
Three passes	520	650	10

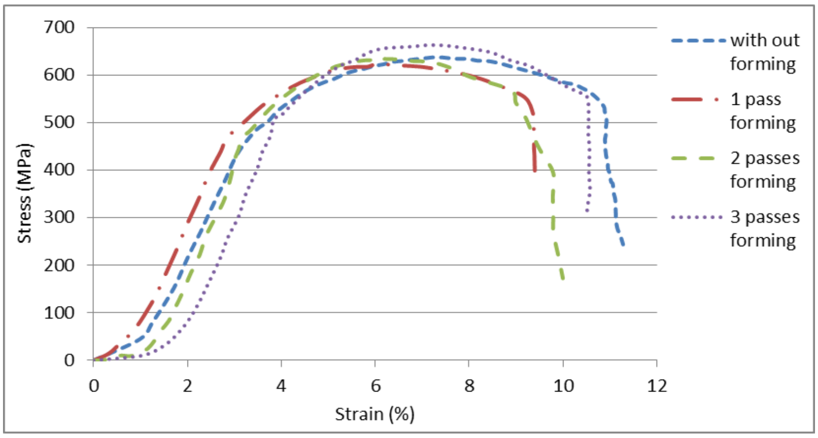

Figure 3. Engineering stress-strain curve of the sheet before and after deformation.

As it is observed by applying the forming process by press, the mechanical properties, including yield strength, tensile strength and fracture strain are reduced compared to the initial sample. The reason for reducing the mechanical properties is due to the Bauschinger Effect and the disappearance of the microstructure order. The metallographic image is shown in fig .4.

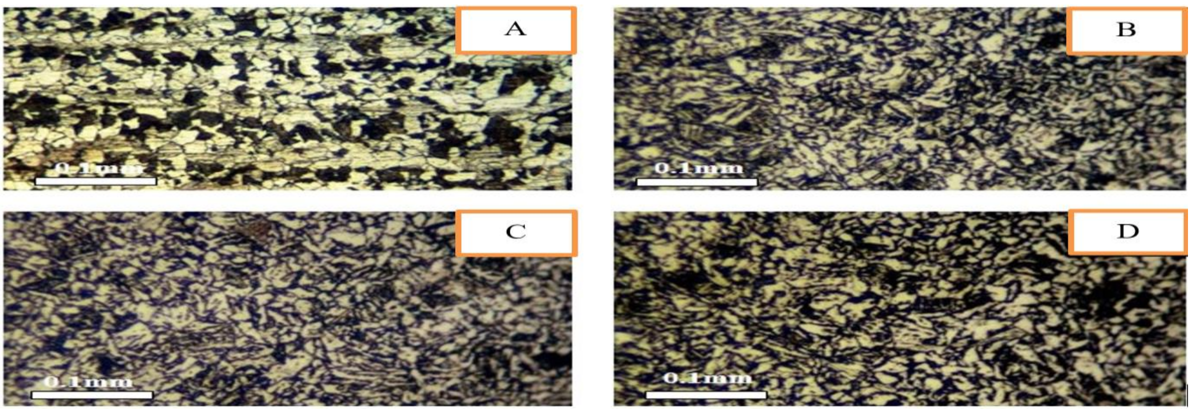

Figure 4. Optical micrograph A537 Cl2 steel specimens before and after pressing, A) Rolling sheet (before pressing), B) One pass, C) Two passes, D)Three passes.

In metallographic image, the disorganization of the microstructure after the first deformation is quite obvious. On the other hand, the bonding between the grains by the forming process is completely lost. The Bauschinger Effect can play an important role in the reduction of mechanical properties after forming process by pressing the initial sheet. In bending process steel plate, this phenomenon is very important. Also the metals become cold work and when they are subjected to tensions with opposite sign, Soft Work occurs on them. The Bauschinger Effect mechanism is hidden during the Cold Work process. Orowan mentioned that during plastic deformation, dislocations in nodes happens in the accumulated obstacles and eventually lead to cell formation [11]. After unloading, due to the stability of the structure from mechanical viewpoint, the dislocation lines cannot move a lot. In this regard, when the loading is reversed, a number of dislocation lines in lower tensile can move in a great distance, because the barriers behind dislocations are likely not so tightly and close to each other, as similar as those barriers in front of them. In fact, this will lead to the initial yield in a lower tension when the loading is reversed [11]. The reason for the reduction of tensile strength and yield tension in the deformed sample in comparison to the initial sample, is the Bauschinger Effect and the loss of bonding and texture in the microstructure. Considering this fact that deformation of these specimens were Cold Work and they were done by compressive force, therefor, the Bauchinger phenomenon is occurred due to the residual compression stress in the grains after the tensile plastic deformation [12]. Metallographic results showed that in the initial sample, the grains are drawn in the same direction as the direction of the rolling process that by forming process by pressing force of structure pressing and the direction of the grains, they are changed and the arrangement of the microstructure and texture disappeared which is very important in reducing the yield strength and tensile strength. In this regard, by repeating the forming process in two and three stages, the disarrangement of the microstructure was reduced and the grains were applied in line by pressing force. As a result, it improved the mechanical properties. So that in the sample that three stages were subjected to cold deformation, better tensile properties were achieved than the initial sample. The results of the impact test at temperature of -49 ° C are shown in Table 3.

Table3: The impact test energy at -49 °C of the sheet before and after deformation

Sample Name	Impact test energy at -49 °C
Initial Plate	220 J
One Pass	170 J
Two Passes	183 J
Three passes	215 J

It is observed that the highest impact energy is specific to the rolling sample, which has a number of grains in the same direction and its structure has boding, and also the number of grains with the sharp corners in the microstructure is less than the deformed sampels. Paying attention to the fact that the best microstructure for integrating the toughness with the strength, is stability of the tiny particles that have a strong connection with the context so that it prevents from the formation of the hole [13] that this microstructure in the rolling sample in obvious shown in metallographic image (Figure 4. A). Therefore, by performing the forming process and removing the existing order in the microstructure and changing the direction of the grains, some holes are formed in the microstructure and the grains boundaries. In addition, because of the forming process, the grains are crushed and the number of grains with sharp edges is increased and this leads to the reduction of the impact energy. By repeating the forming process stages, increasing the discipline of the microstructure, and putting the grains in the order, and also disappearing the holes, the impact energy increases. In Fig. 5, the fracture surfaces of the initial sample and the deformed sheets are shown in one, two and three stages of the process.

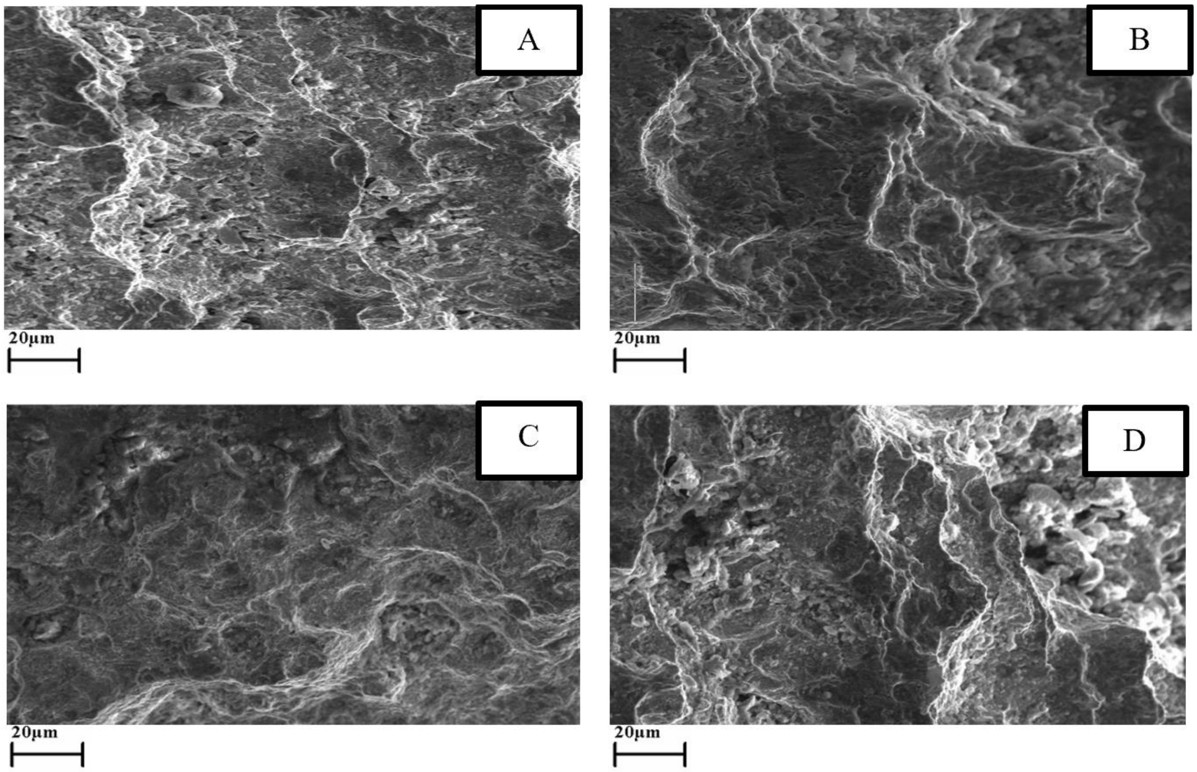

Figure 5. SEM image of the fracture surface after impact test before and after pressing, A) Rolling sheet (before pressing), B)One pass, C) Two passes, D)Three passes.

The presence of the dimples at the breaking surface of the initial sheet (Figure 5 A) shows the soft fracture. By doing the forming process at the first stage of formation (Figure 5. B) and the disorganization of the microstructure, disappearing of the boding between the particles, and the different arrangement of the grains from each other, the number of the dimples at the breaking surface is greatly reduced and the rocky surface at the breaking surface are more visible that is due to the brittle fracture. By applying the second stage of the forming process (Figure 5 - C), the structure becomes more uniform and it increases at the breaking surface by the presence of the dimples in comparison to the first stage of the forming process that is besides the surface of the brittle fracture and due to this fact the soft-brittle fracture is confirmed. At the breaking surface of the third stage of the forming process (Figure 5. D) by increasing the organization of the microstructure and by getting in a more uniform direction, in comparison to the previous grains, the presence of dimples is more than before, and the soft fraction occurs.

4- Conclusions

1) By applying the forming process by pressing on metal sheet of A 537Cl2, the tensile properties were reduced which can be attributed to the Bauschinger Effect and the loss of bonding between grains.
2) The results of tensile and Metallographic tests show that by repeating the forming process, the tensile properties improves due to the reduction of the disorganization in the microstructure, so that in the sample that is under the three stages of the cold deformation, the tensile properties become better than the initial sample.
3) The results of the Impact Test at temperature of -49°C showed that by applying the forming process and due to the disorganization of the microstructure and the formation of grains with sharp corners, the resistance to the impact will be reduced first and then by repeating the process and reducing the amount of disorganization in the microstructure and disappearing of the holes, the impact increases.

Acknowledgements

I am sincerely grateful to the cooperation of the managing director of Arak Metallurgical Engineering Group and the experts in field of production and the laboratory who cooperated in this research.

References

[1] T. U. Marston and W. Server, “Assessment of weld heat affected zones in a reactor vessel material”, Journal of Engineering Materials and Technology, 1978, Vol. 100, No. 3, pp.267-271
[2] ASTM, A 537/A 537M, Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese- Silicon Steel.
[3] X.S. Du, Y.J. Su, J.X. Li, L.J. Qiao, W.Y. Chu“Stress corrosion cracking of A537 steel in simulated marine environments” Corrosion Science, 2012, Vol. 65, pp. 278-287
[4] Ostensson B, “The fracture toughness of pressure vessel steel at elevated temperatures Reliability of Reactor Pressure Components”, 1981, IAEA.
[5] J. T. McGrath, R. S. Chandel, R.F. Orr, and J.A. Gianetto, “A review of factors affecting the structural integrity of weldments in heavy wall reactor vessels”, Canadian Metallurgical Quarterly, 1989, Vol. 28, No. 1, pp. 75-83.
[6] Y. Yang, “The effect of submerged arc welding parameters on the properties of pressure vessel and wind turbine tower steels”, 2008, Thesis (M.Sc.), University of Saskatchewan, Saskatoon, Saskatchewan.
[7] H. Huang, W. Tsai, and J. Lee, “The influences of microstructure and composition on the electrochemical behavior of A516 steel weldment”, Corrosion Science, 1994, Vol. 36, No. 6, pp. 1027-1038.
[8] J.H. Yoon, B. S. Lee, Y. J. Oh, and J. H. Hong, “Effects of loading rate and temperature on J-R fracture resistance of an SA516-Gr. 70 steel for nuclear Piping”, International Journal of Pressure Vessels and Piping, 1999, Vol. 76, pp. 663-670.
[9] Metals Handbook, “ Properties and selection: irons, steels and high-performance alloys”, 1990, Vol. 1, ASM International, Materials Park, OH, pp. 389-423.
[10] ASME Sec VIII Div 1, “Rules for construction of pressure vessels”,2013.

[11] E. Orowan, ‘‘Internal stresses and fatigue in metals’’, 1959, New York, Elsevier Publishing Company.
[12] S. T. Rolfe, R. P. Haak, J. H. Gross, "Effect of state of stress and yield criterion on the bauschinger effect ",1968, United States Steel Corporation, Applied Research Laboratory, Monroeville, Pa.
[13] Richard W.Hertzberg, "Deformation and fracture mechanics of engineering materials", 1996, 2nd ed, John Wiley & Sons.